EFFECT OF POLYVINYL ALCOHOL ORGANIC COMPOUND ON TENSILE STRENGTH OF ORDINARY PORTLAND CEMENT (OPC) CONCRETE

AISYAH BT. RAMLE

CIVIL ENGINEERING

UNIVERSITI TEKNOLOGI PETRONAS

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by

`Aisyah bt. Ramle

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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(CIVIL ENGINEERING)

Approved by,

____
(Ms. Nabilah bt. Abu Bakar) o/b DR VICTOR R MACAM

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

`AISYAH BT. RAMLE

ABSTRACT

Many studies have been carried out to increase the tensile strength of concrete but in this project, it attempts to study on how the organic compound can affect the strength of concrete. Naturally, concrete is strong in compression but it is weak in tension. This weakness also is cause by the existence of interfacial transition zone between the aggregate and cement paste. Hence, the main focus of this project is to improve and enhance the tensile strength in concrete or mortar. Because of that, a new method is implemented by finding out the suitable organic compound which can be added in concrete to solve the problem. Hence, polyvinyl alcohol (PVA) is chosen. By using this material, PVA will increase the concrete tensile strength and slightly changes in structure and composition in the interfacial transition zone. The PVA properties, applications of PVA in concrete, factors affecting concrete strength and suitable tests to determine the concrete or mortar tensile strength also are discussed in this report. Thus, a research might lead to a stage where PVA will replace the other materials which can raise the tensile strength of concrete.

The successful completion of this project would not have been possible without the assistance and guidance of many individuals whose contribution has been tremendous.

First and foremost, I would like to thank God Almighty for giving me a strength and guidance towards completing this project.

Then, I would like to express sincere gratitude and appreciation to my project supervisor, Dr. Victor R. Macam and Ms. Nabilah Abu Bakar for their numerous valuable input and guidance throughout this project.

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ABBREVIATIONS AND NOMENCLATURES

$Ca(OH)_2$	Calcium Hydroxide
C-S-H	Calcium Silicate Hydrate
EDX	Energy Dispersive X-Ray
ITZ	Interfacial Transition Zone
OPC	Ordinary Portland Cement
PPE	Personal Protective Equipment
PVA	Polyvinyl Alcohol
SEM	Scanning Electron Microscope
SSD	Saturated Surface Dry
w/c	Water to Cement Ratio

CHAPTER 1

INTRODUCTION

This chapter gives the preface to the project. In this chapter, the background of study towards this project is revealed. This chapter also discussed the subject and situation that led to the objectives of this project. In the last section of this chapter, the scope and the boundary of the project are clarified.

1.1. Background of Study

Concrete has been the major instrument for providing stable and reliable infrastructures since the days of the Greek and Roman civilizations. It is a construction material commonly made by mixing Portland cement, aggregate, water and admixtures. When water is added to cement, each of the compounds undergoes a chemical process known as hydration and contributes to strength, creating a stone-like material.

Concrete has many advantages that add to its popularity. First, it is economical when ingredients are most readily available. Concrete's long life and relatively low maintenance requirements increase its economic benefits. Concrete also is a non-combustible material which makes it fire-safe and able to withstand high temperatures. The ability of concrete to be cast to any desired shape and configuration is an important characteristic that can offset other shortcomings. Concrete can be cast into soaring arches and columns, monolithic sections and complex hyperbolic shells. In addition, concrete possess excellent resistance to water, strong and wear resistant (durable).

Despite its numerous advantages, concrete does have limitations in its properties. Concrete has a relatively low tensile strength, low ductility, low strength-to-weight ratio and is susceptible to cracking. The correct proportion of ingredients, placement and curing are needed in order to obtain optimal properties of concrete.

1.2. Problem Statement

Concrete has relatively high compressive strength but significantly lower tensile strength. Tensile strength of concrete is about 10% of its compressive strength. In fresh concrete, a water-cement ratio (w/c) gradient develops around the aggregate particles during casting, resulting in a different microstructure of the surrounding hydrated cement paste. This zone around the aggregate is called the interfacial transition zone (ITZ).

ITZ is the weakest link in the normal concrete matrix and significantly affects the properties of the concrete. Its thickness is in range of 40–50 μm. Since microcracks always presented in ITZ hence failure occurred by concrete is an almost start from this zone.

The adhesion between aggregate and cement paste within the transition zone is one of the factor that governs the concrete strength. There are also other factors which may contribute to the strength of concrete. Because of that, a new method must be implemented in order to improve the interfacial transition zone hence increase the tensile strength of concrete.

1.3. Objectives and Scope of Study

The aims of this research are:

i. To apply the polyvinyl alcohol (PVA) in the concrete or mortar mixing where it can act as a repair material and increase the bond strength between aggregate and paste.
ii. To improve and increase the tensile strength of concrete.
iii. To improve the structure and composition in the interfacial transition zone in concrete.
iv. To determine the optimum mix design by incorporating polyvinyl alcohol as an organic compound.

The scope of study for this project is to investigate the properties of PVA and its influence towards the concrete properties plus finding out the reason why concrete low in tensile strength. Once it is already mixed and cured, the tests shall be conducted to examine the performance of concrete where it will be subjected to strength and its composition.

Different concentration of PVA will be used throughout the experiments so that the optimum mix design will be obtained. Besides that, the aggregate with different surface conditions will be taken into account in order to investigate its influence towards concrete properties and strength.

CHAPTER 2
LITERATURE REVIEW

2.1. What is Ordinary Portland cement (OPC) Concrete?

In its simplest form, concrete is a mixture of paste and aggregates. The composition of Portland cement and aggregates will produce a paste which coats the surface of the fine and coarse aggregates. Through a chemical reaction called hydration, the paste hardens and gain strength to form a rock-like mass.

Portland cement is hydraulic cement that hardens by interacting with water and forms water-resisting compound when it receives its final set. It is highly durable and produces high compressive strengths in mortars and concretes compared with nonhydraulic cements such as gypsum and lime which absorbs water after hardening. Portland cement is made of finely powdered crystalline minerals composed primarily of calcium and aluminium silicates. The addition of water to these minerals produces a paste which when hardened, it becomes of stone-like strength (E. G. Nawy, 2001).

According to ASTM C150, there are five types of Portland cement. For ordinary Portland cement, it is known as Type 1 Portland cement. This cement is commonly referred to as general purpose Portland cement. Type 1 Portland cement is suitable for most construction applications especially when there is no exposure to sulfates in the soil or groundwater (A. M. Neville, 2005). Table 2.1 shows the typical composition of ordinary Portland cement.

Table 2.1. Typical Compound Composition of OPC (A. M. Neville, 2005)

Chemical Name	Chemical Formula	Abbreviation	% wt
Tricalcium Silicate	$3CaO.SiO_2$	C_3S	50
Dicalcium Silicate	$2CaO.SiO_4$	C_2S	25
Tricalcium Aluminate	$3CaO.Al_2O_3$	C_3A	12
Tetracalcium Aluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF	8

Hydration process creates the strength of cement paste. Recrystallization will be produced through this chemical process in the form of interlocking crystals, producing the cement gel which has high compressive strength when it hardens. The higher percentages of C_3S hence the higher early strength of Portland cement will be obtained. Later strength levels become greater with higher percentage of C_2S if moist curing is continuous. C_3S contributes to the strength developed during the first day after placing the concrete because it is earliest to hydrate (E. G. Nawy, 2001).

Based on Portland Cement Association, aggregates such as sand, gravel or crushed stone are inert granular materials which come along with water and cement. Aggregates need to be clean, hard, and free from chemical and clay in order to obtain good concrete mixing and to avoid deterioration. Aggregates can minimize segregation and degradation and prevents contamination. In having a good mixing proportion, some characteristics of aggregate should be considered. It includes grading, durability, particle shape and surface texture, abrasion and skid resistance, unit weights and voids and lastly, absorption and surface moisture. The choice of aggregate is determined by the proposed use of the concrete. Normally, it should be well-graded to improve packing efficiency and minimize the amount of cement paste needed. This makes the concrete more workable.

Another essentials ingredient of concrete is water. Water mix with cement forms a paste through the hydration process. Mixing water need to be pure in order to prevent the side effects which can weaken the concrete and interfere the hydration process. Besides that, the role of water is very important as impurities in water may interfere with the setting of cement, may affect the concrete strength adversely or cause staining of its surface and also lead to corrosion to reinforcement. Hence, the suitability of water for mixing and curing purposes should be considered in obtained a workable concrete (A. M. Neville, 2005).

2.2. Strength of Concrete

The strength of concrete is very much dependent upon the hydration reaction. Water plays a critical role, particularly the amount used. The strength increases when less water is used to make concrete. Concrete is actually mixed with more water than is needed for the hydration reactions. This extra water is added to give concrete sufficient workability.

Water to cement (w/c) ratio is important to determine the strength of concrete. Established by Duff Abrams in1999, he found that when concrete is fully compacted, its strength is taken to be inversely proportional to the w/c ratio (A. M. Neville, 2005).

Low w/c ratio leads to high strength but low workability. High w/c ratio leads to low strength but good workability. The relationship of (w/c) ratio and strength is as shown in Figure 2.1.

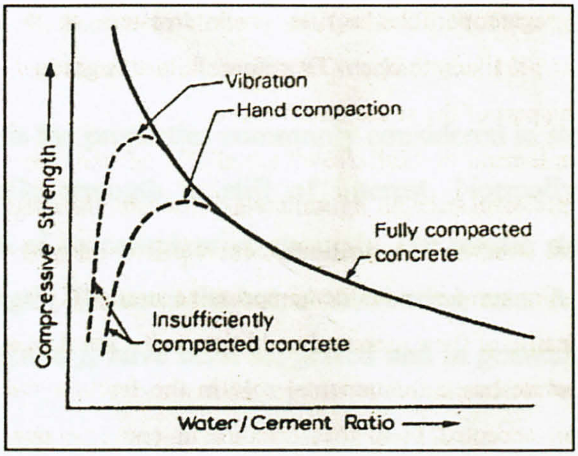


Figure 2.1. The relation between strength and water to cement ratio of concrete (A. M. Neville, 2005)

Aggregate characteristics are also very important where it can determine the plastic properties of concrete mixture. It not only affects the concrete mixture proportions but also the behavior of fresh and hardened concrete. On 2006, K. Mehta & P. J. M. Monteiro discovered that there is some evidences where the strength of concrete, particularly the flexural strength can be affected by the aggregate texture during early age. A rougher texture seems to help the formation of a stronger physical bond between cement paste and aggregate but this effect may not be so important later since the chemical bond will exist. The shape and porosity of aggregate also influences the properties of concrete.

Another factor to determine the concrete strength is time. Concrete hardened as time passes. The hydration reactions get slower and slower as the tricalcium silicate hydrate forms. It takes a great deal of time for all of the bonds to form. It is common to use 28-day test to determine the relative strength of concrete.

Concrete strength also is affected by the addition of admixtures. There are several types of admixtures for instance air-entraining, water reducing, superplasticizer and each of them will give different kinds of uses or advantages to concrete in order to enhance the strength and properties of concrete.

2.3. Tensile Strength

Compressive strength is the properties commonly considered in structural design but for certain purposes tensile strength is still of interest. Normally, tensile strength of concrete is about 10% of its compressive strength. The tensile strength, f_t, increases as the compressive strength, f_c, increases but in decreasing rate. A number of empirical formulae connecting f_t and f_c have been suggested and in general, the equation goes to be:

$$f_t = k(f_c)^n$$

where k and n are coefficients. Normally, n value is 0.7 meanwhile k value could be 0.3, 0.2 or 0.12, depending on the loading conditions. However, k value is not very important since the differences between the various expressions are not large.

The most important thing is the power exponent used must be low so that the splitting strength is overestimated at low compressive strengths and underestimated at high compressive strength (A. M. Neville, 2005).

2.4. Interfacial Transition Zone (ITZ)

The weakest region in ordinary concrete exists due to the bonding between coarse aggregates and cement paste. On first upon loading, this link will fail and initiates fracture of the concrete. This phenomenon occurs due to presence of ITZ between aggregate and cement paste. ITZ is a porous calcium hydroxide-rich layer. Its thickness is approximately 40-50 μm (J. H. Kim and R. E. Robertson, 1998).

On 2006, P. K. Mehta and P. J. M. Monteiro discovered that the presence of microcracks is a major factor which contributes to poor strength of ITZ. There are several factors can influence the amount of microcracks including aggregate size and grading, cement content, water-cement ratio, degree of consolidation of fresh concrete, curing conditions, environment humidity and thermal history of concrete. For instance, the formation of thick water film around the large coarse aggregate can cause the ITZ in this condition susceptible to crack when subjected to influence of tensile stresses induced by differential movement between aggregate and hydrated cement paste. In other words, a concrete can have microcracks in the ITZ even before a structure is loaded. Moreover, cracks propagate rapidly at a much lower stress level under tensile loading. This is why concrete fails in a brittle manner in tension but is relatively tough in compression. This is also the reason why the tensile strength is much lower than the compressive strength of concrete.

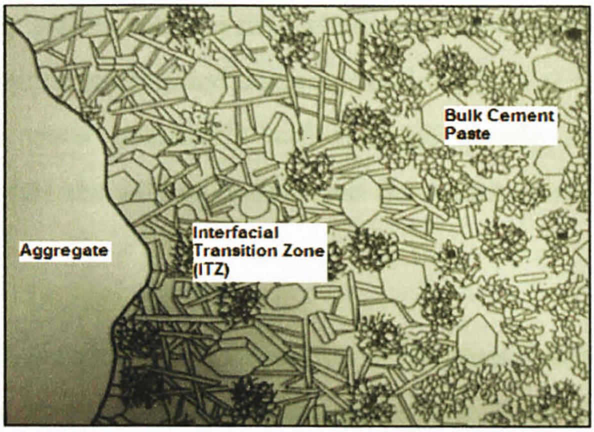
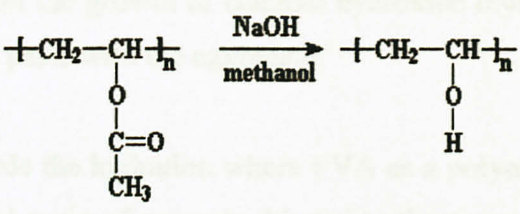


Figure 2.2. Diagrammatic representation of the interfacial transition zone and bulk cement paste in concrete (P. K. Mehta and P. J. M. Monteiro, 2006)

2.5. Polyvinyl Alcohol (PVA)

Polyvinyl alcohol known as vinyl alcohol polymer, PVA or ethanol homopolymer is an environmental friendly material. It is also a water-soluble synthetic resin prepared by polymerization of vinyl acetate as in Figure 2.3, followed by partial or complete catalyzed hydrolysis. It is white soluble high-molecular compound, not soluble in ordinary organic solvents. PVA exists in white solid color with excellent tensile stress, mouldability, impact strength, wear resistance and excellent electrical insulation.



poly(vinyl acetate) poly(vinyl alcohol)

Figure 2.3. Polymerization of vinyl acetate to create polyvinyl alcohol

PVA comes in varies grades and physical characteristics depending on its molecular weight (degree of polymerization) and degree of hydrolysis. For fully hydrolyzed PVA, it can decrease the water sensitivity and increase tensile strength. For partially hydrolyzed PVA, it has the ability to increase the water sensitivity and is as good dispersing agent.

In their research, J. H. Kim and R. E. Robertson (1998) found that the small addition of PVA to cement paste results a great impact especially to bond strength and interfacial transition zone. The aggregate-paste bond strength generally increased with increase in PVA content in paste. There are some changes occurred in structure and composition of ITZ by the presence of PVA. For ITZ structure, there was a decreased in ITZ thickness compared to sample without PVA. Almost no porosity can be seen, although small region of $Ca(OH)_2$ platelets are occasionally observed at the interface. The small addition of PVA also greatly reduced the formation of flocculated structures by the cement particles. This is because PVA tends to disperse or deflocculate the cement particles near the aggregate surface and prevents the formation of a porous layer as well as reducing bleeding. For ITZ composition, the amount of calcium silicate hydrate (C-S-H) increased while decreased the amount of calcium hydroxide during the hydration of cement. When PVA is used, the PVA molecules are able to adsorb on the aggregate surface. This will prevent the growth of calcium hydroxide crystals where it forms the poor bonding of cement paste with the aggregate.

The usage of PVA retards the hydration where PVA as a polymer, coats the surface of hydrated and unhydrated grain of cements, hindering the approach of water molecules to come in contact with cement particles. But at the same time, the compressive strength will increase and porosity will decrease. These effects are due to chemical interaction between PVA and cement, forming some new compounds that fill the pores and improve the bond between the cement (N. B. Singh, S. Rai, 2000).

In addition, on 1999, R. Rixom & N. Mailvaganam found that PVA can be classified in Class A of antiwashout admixtures where it can increase the viscosity of the mixing water hence improved the resistance to segregation. It also is able to perform as an adhesive. This type of admixture also is called as viscosity – enhancing admixtures or cohesion – inducing admixtures. This statement also can be proved through the experiment done by J. H. Kim and R. E. Robertson (1998) where they stated that PVA tend to retard flocculation of the cement grains and increased the efficiency of deflocculation during mixing and vibration because of the increased viscosity.

2.5.1. BF17W (Fully – Hydrolyzed Polyvinyl Alcohol)

BF17W is one of fully hydrolyzed grade in PVA. It comes in powder form where we need to dissolve it with heated water to form a solution which is looks like an adhesive or glue in certain concentration desired. Table 2.2 shows the typical properties of BF17W (Fully – Hydrolyzed Polyvinyl Alcohol).

Table 2.2. Typical Properties of BF17W

Items	Unit	Results
pH	None	6.00
Viscosity	cps	28.9
Hydrolysis	mole %	96.93
Volatile	wt %	2.62
Ash	wt %	0.31
Colour	None	White to ivory

2.6. Tensile Strength Tests

Tensile testing is commonly used to determine the maximum load of tensile strength that a material or product can withstand. There are three types of test used to determine the tensile strength of concrete which are direct tension test, flexure loading test and splitting tension test. However, only two tests are considered, flexural loading test and splitting tension test because direct tension test of concrete is seldom carried out mainly cause by the specimen holding introduce secondary stresses that can not be ignored.

2.6.1. Flexural Loading Tests

In this test, a concrete beam is subjected to flexure using symmetrical two-point loading until failure occurs. Because the load points are spaced at one-third of the span, the test is called a third-point loading test. In BS 1881 : Part 118 : 1983, it prescribes third-point loading on 150 x 150 x 750 mm beam supported over a span of 450 mm. Another test which is included in this test is center-point loading but it is very rarely used (A. M. Neville, 2005).

Flexural strength is expressed in terms of the modulus of rupture which is the maximum stress at rupture from the flexural formula is:

$$\boldsymbol{R} = \frac{\boldsymbol{PL}}{\boldsymbol{bd^2}}$$

Where; R = modulus of rupture
P = maximum indicated load
L = span length
b = width of the specimen
d = depth of the specimen

(P. K. Mehta & P. J. M. Monteiro, 2006)

2.6.2. Splitting Tension Test

A concrete cylinder is placed between the platens of the testing machine. The advantage of using this test is it can be used for both compression and tension tests. For compression test, a concrete cylinder is placed vertically between the platens and the load is increased until failure by indirect tension in the form of cracking along the vertical height takes place. Meanwhile, for tension test, the mechanism of testing is the same but the concrete cylinder is placed horizontally and failure will be obtained along the vertical diameter. It is simple to perform and gives more uniform results compared to other tension tests. The strength obtained is almost close to direct tensile strength which is about 5 – 12% higher but in case of mortar, the test will yield too low of results.

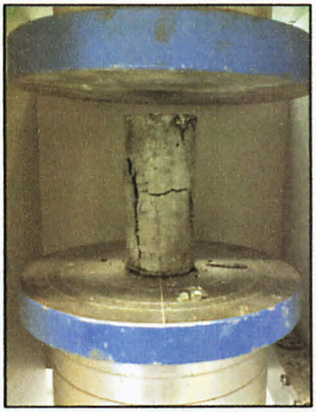


Figure 2.4. Compression test

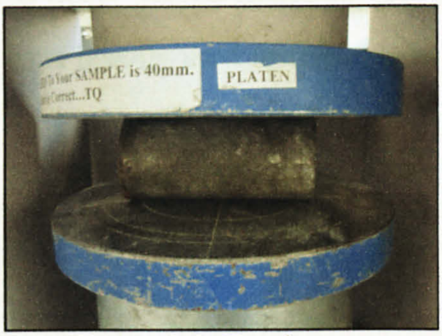


Figure 2.5. Tension test

The tensile strength can be determined by equation below:

$$T = \frac{2P}{\pi LD}$$

Where; T = tensile strength

P = failure load

L = length of specimen

D = diameter of specimen

(A. M. Neville, 2005)

2.7. Scanning Electron Microscope (SEM) Analysis

The Scanning Electron Microscope (SEM) is a microscope that uses electrons rather than light to form an image. Its imaging method allows separation of the two functions of a microscope, localization and information transfer. The SEM utilizes a very fine probing beam of electrons which sweeps over the specimens to emit a variety of radiations. Compare to other microscopy research, it is very often the preparative methodology that determines the success or failure of the research. A specific requirement of SEM preparation is that the material must be dried. This preparative step must be done very carefully to minimize surface tension effects.

By using SEM, it has a large depth of field which allows a large amount of the sample to be in focus at one time. The SEM also produces images of high resolution which means that closely spaced features can be examined at a high magnification. The combination of higher magnification, larger depth of focus, greater resolution and ease of sample observation makes the SEM one of the most heavily used instruments in the research areas today.

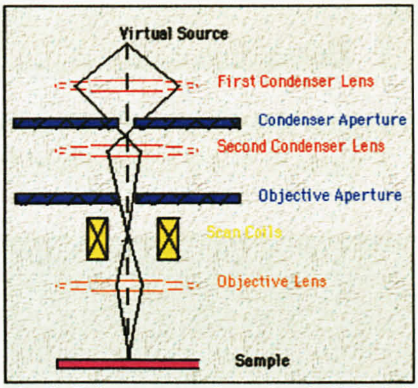


Figure 2.6. Diagram of typical SEM function

2.8. Energy Dispersive X-Ray (EDX) Analysis

Energy Dispersive X-Ray is sometimes referred to EDS or EDAX analysis. It is a technique used to identify the elemental composition of the specimen or an interest thereof. The EDX analysis system works as an integrated feature of a scanning electron microscope (SEM) and can not operate on its own without the latter. It is also not a surface science technique because the X-rays are generated in a region about 2 microns in depth. An electron beam strikes the surface of a conducting sample. The energy of the beam is typically in the range 10-20 keV. This causes X-rays to be emitted from the point of the material. The energy of the X-rays emitted depends on the material under examination.

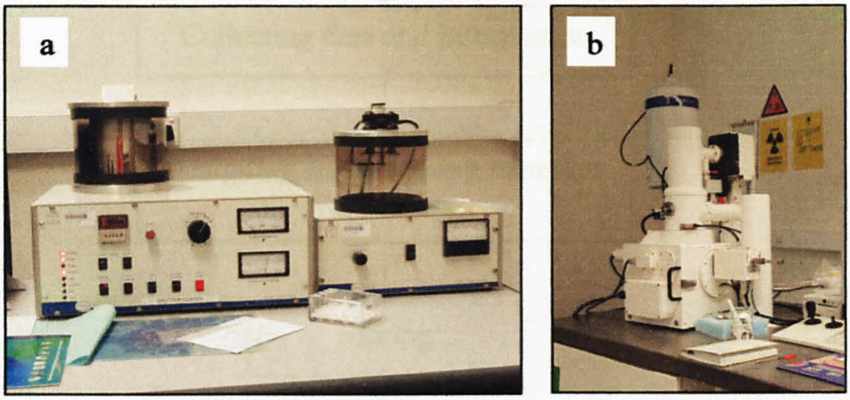


Figure 2.7. The apparatus used for SEM and EDX analysis which are, a) sputter coater and b) Oxford Instruments INCA Energy X – ray detector

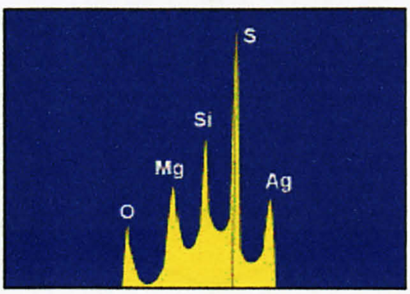


Figure 2.8. Example of EDX spectrum

CHAPTER 3

METHODOLOGY

Figure 3.0 shows the research methodology that will be carried out in two semesters. It starts with planning all works required to conduct the research and lastly analyze and conclude the results obtained from the tests.

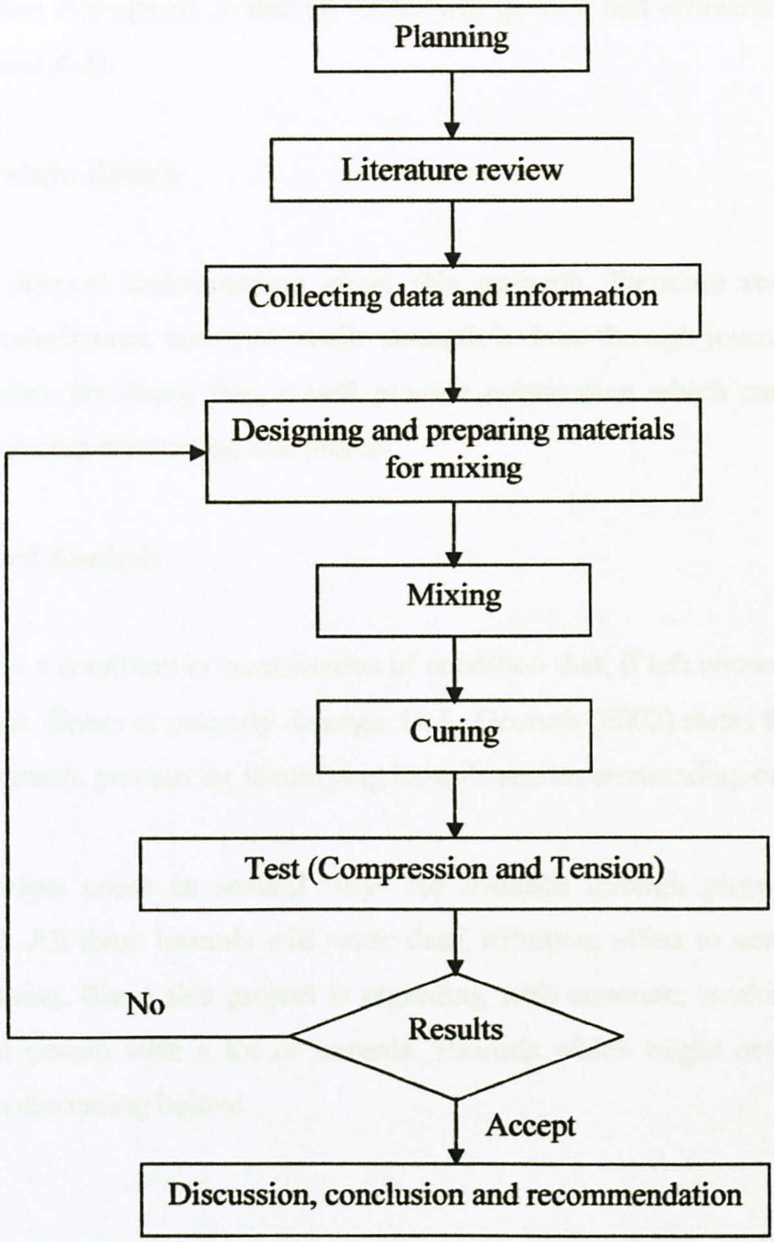


Figure 3.0. Flowchart of research methodology

3.1. Project Plan

Planning is very important to achieve the objectives stated. Good planning will drive this project smoothly. At early stage, much attention goes to literature review as it gives information and basic understanding for this project. Literature review is then followed by laboratory works. All laboratory works will be done throughout the second semester to fulfill the study of this project. In addition, the milestone and Gantt chart for this research also is prepared so that all works will go well and efficiently (*Refer Appendix A-1, A-2 and A-3*).

3.2. Literature Review

To have deepest understanding about this research, literature review on concrete, chemical admixtures, tests and tensile strength is done through journals, books, articles and websites. By doing this, it will provide information which can make them as a guideline during conducting this project.

3.3. Hazard Analysis

A hazard is a condition or combination of condition that, if left uncorrected, may lead to an accident, illness or property damage. D. L. Goetsch (2003) states that hazard analysis are a systematic process for identifying hazards and recommending corrective action.

Hazard might come in several ways for instance through physical, chemical and biological. All these hazards will cause deaf, irritation, affect to nervous system, brain and breathing. Since this project is regarding with concrete, working in concrete lab exposes a person with a lot of hazards. Hazards which might occur and prevention method is discussing below:

3.3.1. Hazard Checklists

Hazards will occur due to unsafe act and conditions. For instance:

- Poor housekeeping
- Noise from sieving machine
- Improper lifting
- Improper procedures and guarded equipments

An article dated October 10, 2005 by Science Lab.com states that the using of polyvinyl alcohol is possible to create a hazard to human. It is slightly hazardous which can cause irritation to eyes and skin, disturb the digestion and inhalation system.

Another article published by OSHA dated on April 22, 2008 mentioned that wet Portland cement can damage the skin where it is caustic, abrasive and have drying properties where it can cause skin inflammation. The trace amounts of hexavalent chromium [Cr(VI)] in Portland cement is also harmful to skin since it is a toxin. Hence, good practice in handling the materials is important while conducting the laboratory works.

3.3.2. Hazard Prevention and Reduction

In order to prevent accident and illnesses, the prevention method should be applied. In concrete lab, we can reduce the risk of unsafe conditions by:

- Practice good housekeeping
- Follow the procedures and instruction by lab technician
- Use proper lifting method
- Use appropriate personal protective equipment (PPE)
- Follow all the rules provided by laboratory

3.4. Tools and Materials

The tools and materials needed to prepare PVA solution are distilled water, BF17W polyvinyl alcohol, a hot plate with magnetic stirrer, steel stirrer, 1 liter beaker and thermometer. Meanwhile, an ordinary Portland cement, aggregate with size gaping from 10mm to 0.15mm, sieving machine, cylinder mould, pail and tray, concrete mixer, scrapper and vibrating table are needed in order to prepare and test the mortar where it will subjected to tensile and compressive strength, respectively.

3.5. Experiment

Two experiments will be conducted which are:

i. Using saturated surface dry (SSD) aggregate with three different concentrations of polyvinyl alcohol solution
ii. Using dry aggregate with three different concentrations of polyvinyl alcohol solution

3.5.1 Planning and Details

Main tests	: Compression and tension tests
Additional tests	: SEM and EDX analysis
Sample	: Mortar
Sample size	: Cylinder (60 mm x 120 mm)
Test days	: 3^{rd}, 7^{th} and 28^{th} days
No. of samples	: Control (21 samples), 1% PVA (21 samples), 2% PVA (21 samples) and 3% PVA (21 samples)

3.5.2 Variables

i. Two types of aggregate conditions which are saturated surface dry (SSD) aggregate and dry aggregate.

ii. Three different concentrations of PVA solution which are 1%, 2% and 3%.

The mix is designed based on fraction of aggregate to cement to water. The water to cement ratio is 0.35 and aggregate to cement ratio is 2:1. All procedures to conduct the experiment are according to British Standard (BS) Codes and Practices which is BS 1881. Further detailed about mix design calculation and procedures can be referred to *Appendix C* and *Appendix D*.

CHAPTER 4
RESULTS AND DISCUSSION

This experiment was done to prove the early hypothesis where by using the polyvinyl alcohol (PVA), it will help to improve the interfacial transition zone properties and increase the tensile strength of concrete. In this research, different conditions of aggregate were used which are dry and saturated surface dry (SSD) aggregate. The usage of both aggregates will be evaluated by looking at the results obtained. For each case, different concentrations of PVA were applied which are 1%, 2% and 3% and the samples was tested on compressive and tensile strength for 3rd, 7th and 28th days. Three mortar samples were utilized for each test.

To obtain the percentage increase or decrease, the formula used is as below:

$$Percentage = \frac{PVAstrengthvalue - Controlstrengthvalue}{Controlstrengthvalue} x100$$

4.1. Tensile Strength

Subject 4.1.1 and 4.1.2 will discuss on tensile strength based on different aggregate conditions with three different concentrations of polyvinyl alcohol solution samples.

4.1.1. Using Saturated Surface Dry (SSD) Aggregate with Three Different Concentrations of Polyvinyl Alcohol Solution

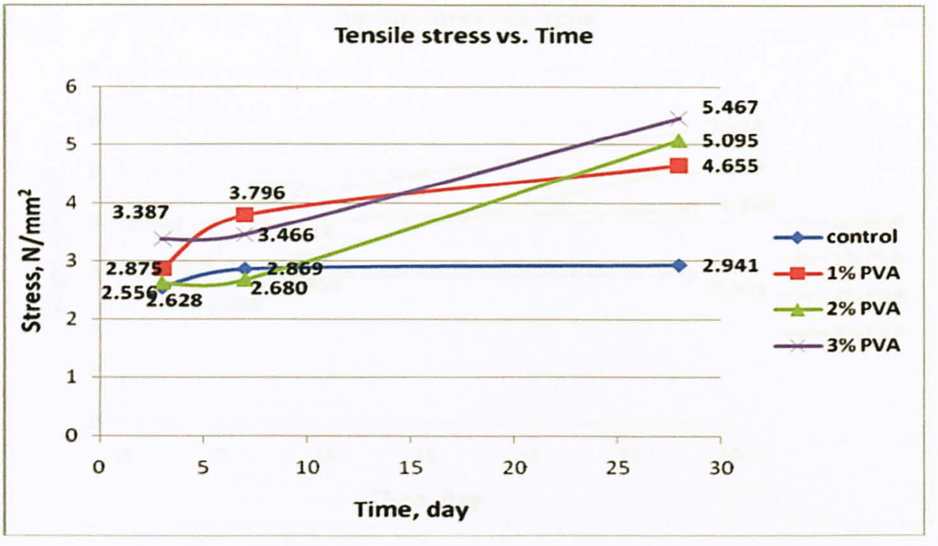


Figure 4.1. Graph of tensile stress vs. time

By observing the graph in Figure 4.1 and referring to the results obtained at day 28, it shows that the sample with the addition of 1%, 2% and 3% increased compare to the control sample in which its tensile stress value is 2.941 N/mm^2. For 1% additional of PVA solution sample, the tensile stress value obtained is 4.655 N/mm^2 where it increased about 58.28%. For 2% and 3% samples, the tensile stress obtained are 5.095 N/mm^2 and 5.467 N/mm^2 with the increasing of 73.24% and 85.89%, respectively.

4.1.2. Using Dry Aggregate with Three Different Concentrations of Polyvinyl Alcohol Solution

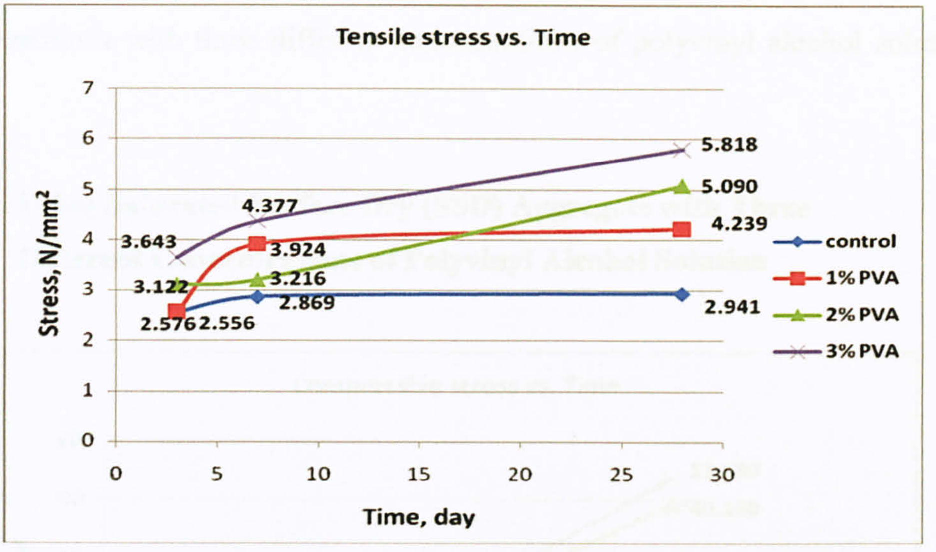


Figure 4.2. Graph of tensile stress vs. time

As shown in Figure 4.2, it is observed that at day 28, the tensile stress value for control specimen is 2.941 N/mm^2 meanwhile the specimen with addition of 1% PVA gives 4.239 N/mm^2. The sample with the addition of 2% and 3% of PVA also gives the higher results than control sample which is 5.090 N/mm^2 and 5.818 N/mm^2. It shows that there is an increment with the addition of 1%, 2% and 3% PVA solution in mortar. It increased at about 44.13% for 1% PVA, 73.07% for 2% PVA and 97.82% for 3% PVA solution compare to the control sample.

From Figure 4.1 and 4.2, it is observed that 1% PVA sample gives rapid hardening strength at day 7 compare to 2% and 3% PVA samples. But as time goes by, 2% and 3% PVA samples is sharply increased in strength compare to 1% PVA sample.

4.2. Compressive Strength

Subject 4.2.1 and 4.2.2 will discuss on compressive strength based on different aggregate conditions with three different concentrations of polyvinyl alcohol solution samples.

4.2.1. Using Saturated Surface Dry (SSD) Aggregate with Three Different Concentrations of Polyvinyl Alcohol Solution

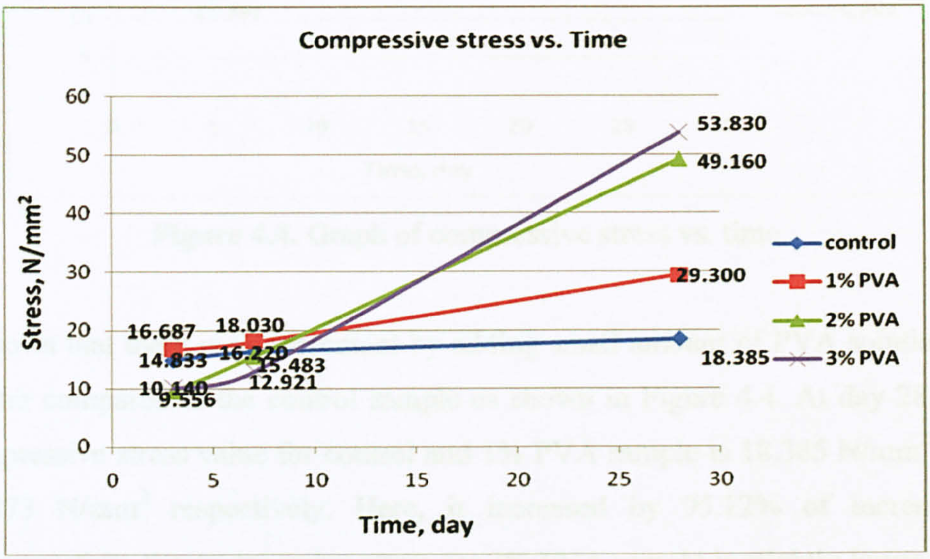


Figure 4.3. Graph of compressive stress vs. time

From Figure 4.3, all samples with the addition of PVA yield high values of compressive stress which are 29.300 N/mm^2 for 1% PVA, 49.160 N/mm^2 for 2% PVA and 53.830 N/mm^2 for 3% PVA. Overall, the using of PVA solution increased the compressive stress of mortar containing saturated surface dry (SSD) aggregate by 59.37%, 167.39% and 192.79%, respectively if comparing all samples with control sample at day 28.

4.2.2. Using Saturated Surface Dry (SSD) Aggregate with Three Different Concentrations of Polyvinyl Alcohol Solution

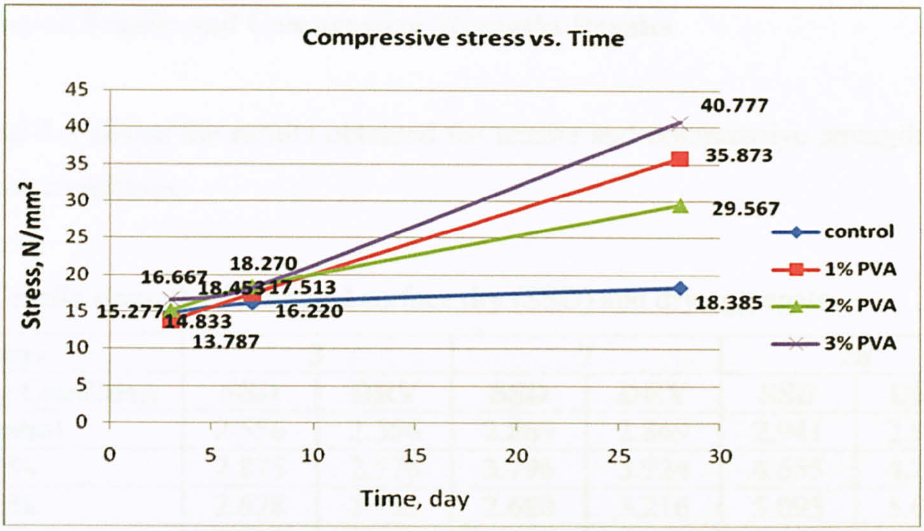


Figure 4.4. Graph of compressive stress vs. time

It shows that there is an increment by adding small amount of PVA solution in mortar compared to the control sample as shown in Figure 4.4. At day 28, the compressive stress value for control and 1% PVA sample is 18.385 N/mm^2 and 35.873 N/mm^2 respectively. Here, it increased by 95.12% of increment. Unfortunately, the compressive stress for 2% PVA sample is slightly lower than 1% PVA sample where its value is 29.567 N/mm^2 but this can be accepted since it is still higher than control sample's result. The addition of 2% of PVA solution yield 60.82% of increment where the stress value obtained is 35.873 N/mm^2. For 3% PVA sample, the compressive stress value is 40.777 N/mm^2 and it is also increased at about 121.79% of increment.

For both conditions as in Figure 4.3 and 4.4, the compressive strength value for 1% PVA sample is not experienced a rapid hardening as tensile strength samples at day 7. After that day, the strength values for 2% and 3% PVA samples increased more than 1% PVA sample. But, compressive strength for 2% PVA sample as in Figure 4.4 gives lower results than 1% PVA sample at day 28. This might because of several inaccuracies during mixing. Supposedly, the value obtained should be higher when higher concentration is used in mixing.

4.3. Summary of Tensile and Compressive Strengths Results

Table 4.1 and 4.2 shows the results obtained for tensile and compressive strengths for both aggregate conditions.

Table 4.1. Tensile strength of saturated surface dry (SSD) and dry aggregate

Days	3		7		28	
Aggregate Condition	SSD	DRY	SSD	DRY	SSD	DRY
Control	2.556	2.556	2.869	2.869	2.941	2.941
1%	2.875	2.576	3.796	3.924	4.655	4.239
2%	2.628	3.122	2.680	3.216	5.095	5.090
3%	3.387	3.643	3.466	4.377	5.467	5.818

Table 4.2. Compressive strength of saturated surface dry (SSD) and dry aggregate

Days	3		7		28	
Aggregate Condition	SSD	DRY	SSD	DRY	SSD	DRY
Control	14.833	14.833	16.220	16.220	18.385	18.385
1%	16.687	13.787	18.030	17.513	29.300	35.873
2%	9.556	15.277	15.483	18.453	49.160	29.567
3%	10.140	16.667	12.921	18.270	53.830	40.777

From the results obtained through the experiment done on different conditions of aggregate and concentrations of PVA solution, it is observed that with the small addition of PVA solution into the mixing proportion, the tensile and compressive strengths are improved for both conditions of aggregate. These effects are due to chemical interaction between PVA and cement paste, improve the bond between them hence increasing the strength of mortar.

When water reacts with cement, the cement particle try to flocculate with each other and blocks the water from being used for hydration process. PVA reacts as a dispersive agent, tend to disperse the water and deflocculate the cement particles near the aggregate surfaces hence prevent the formation of porous layer as well as reduce bleeding so that water can be used by hydration process and aggregate. Besides that, PVA is also known as viscosity-enhancing admixture. This admixture tend to increase the viscosity of mixing water hence increase the efficiency of deflocculating where it slows the packing of particles and affects the strength of mortar.

The usage of different condition of aggregate influences the strength obtained. If dry aggregate is used, sufficient amount of water will absorb into the internal pores of aggregate hence the particles become quickly coated with cement paste and prevent further ingress of water necessary for saturation or water adsorption around the aggregates. This situation will influence the strength of mortar. For SSD aggregate, all pores are filled with water. Thus, water-cement ratio will not affected much and maybe remain at the same level. So, it does not affect the workability of mortar. Since the water-cement ratio is low, the workability will be low thus it will produce high strength mortar.

By looking the results as in Table 4.1 and 4.2, it shows that the usage of dry aggregate gives higher value than SSD aggregate even though some of the strength values for SSD aggregate are higher than dry aggregate, generally. But this can not be simplified by saying that dry aggregate is better than SSD aggregate. It depends because both conditions still increases the tensile and compressive strengths of mortar since strength which is contributes by aggregate may influence by numerous parameters such as shape, texture, size, absorption and moisture content.

By comparing the small addition of PVA samples with control sample at day 28, optimum concentration for both tensile and compressive strengths are as shown in Table 4.3 below.

Table 4.3. Optimum mix design by incorporating PVA in mortar

Aggregate \ Test	Tensile strength	Compressive strength
Saturated surface dry	3% PVA solution (85.89% increased)	3% PVA solution (192.79% increased)
Dry	3% PVA solution (97.82% increased)	3% PVA solution (121.79% increased)

From Table 4.3, optimum concentration for both strengths is 3%. This means that the higher PVA concentration used, the higher results will be obtained. Hence, more chemical reaction between aggregate and cement paste will occur.

For these experiments, saturated surface dry (SSD) aggregate is used in control sample. The SSD condition is the better choice as reference state for the following reasons.

i. It represents the "equilibrium" moisture content of the aggregate in concrete or mortar; that is the aggregate will neither absorb water nor give up water to the paste.
ii. The moisture content of aggregates in the field is much closer to the SSD state than the oven-dry (OD) state.
iii. The bulk specific gravity (BSG) of aggregates is more accurately determined by the displacement method in the SSD condition.
iv. The moisture content can be calculated directly from measurements of apparent BSG using the displacement method.

However, a major disadvantage of using the SSD is that it is not easy to obtain a true SSD condition and therefore many people prefer to use OD state as a reference point.

4.4. Scanning Electron Microscope (SEM) and Energy Dispersive X – Ray (EDX) Analysis

In this test, the specimens used are the mortar with saturated surface dry (SSD) aggregate. It is purposely done to examine the composition changes in the interfacial transition zone (ITZ) with the small addition of PVA compare to the sample without PVA solution. Since calcium hydroxide ($Ca(OH)_2$) and calcium silicate hydrate (C-S-H) are the crucial elements present in interfacial transition zone, only these two chemical elements are consider to be discussed in this chapter. The atomic percentage of calcium and silicate elements of control, 1%, 2% and 3% specimen is shown as in Table 4.4 below.

Table 4.4. Atomic percentage of calcium and silicate element

Element	Silicate, Si (atomic%)	Calcium, Ca (atomic%)
Control	1.98	54.72
1%	5.25	53.71
2%	1.68	21.47
3%	8.32	7.97

From Table 4.4, it shows that the increasing of PVA concentration enhance the silicate element but decrease the calcium element. On 1998, J. H. Kim and R. E. Robertson mentioned that the increasing of calcium silicate hydrate (C-S-H) and decreasing of calcium hydroxide amount may due to the presence of PVA during the hydration of cement. The calcium hydroxide layer which is forms on the aggregate surface at an early stage of hydration prevents the contact of aggregate with C-S-H formed later. This may result in the poor bonding of cement paste and aggregate. Therefore, the PVA molecules are able to adsorb on the aggregate surface and eliminate or prevent the growth of calcium hydroxide. Besides that, calcium is brittle element in mortar. Hence, the replacement of calcium hydroxide with calcium silicate hydrate is important because silicate can give strength to mortar by the formation of C-S-H.

By observing the silicate number in 2% PVA sample, it is found that its value is lower than 1% PVA sample. Supposedly, the value should be higher with increasing percentage concentration of PVA solution. So, this error probably caused by inaccuracy in doing the experiment. To improve this, take several shots from a few samples for each reading and take the average or the best reading.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This project attempts to study the effect of small addition of polyvinyl alcohol (PVA) in concrete in order to determine its ability to improve the interfacial transition zone (ITZ) hence increasing the tensile strength of concrete. In this project, mortar is used as a representative to concrete. Generally, all study objectives are met. Through all tests and analysis done, the presence of PVA increase the tensile and compressive strengths of mortar. This is because PVA is able to disperse the cement particles near the surface aggregate, deflocculated each of them so that mixing water can be used for hydration and aggregate hence reduces bleeding to occur. This is also can prevent the formation of porous layer between aggregate and cement paste which can affect the strength of mortar.

Different conditions of aggregate also can contribute the strength of mortar. Either saturated surface dry (SSD) or dry aggregate, both of them have their own characteristics such as size, texture, grading, shape, absorption and surface moisture which can influence the strength obtained. By using both types of aggregate, they still can increase the tensile and compressive strength depends on its numerous parameters.

ITZ structure contains large, oriented crystal of calcium hydroxide ($Ca(OH)_2$) and less calcium silicate hydrate (C-S-H). By adding the PVA solution, it will help to prevent or eliminate the growth of calcium hydroxide on the aggregate surface which weaken the bond between aggregate and cement paste. Calcium is brittle element but silicate can give strength to mortar by the formation of C-S-H. Hence, the usage of PVA improves the composition of ITZ and increases the tensile strength of mortar.

To widen the knowledge of application of polyvinyl alcohol in concrete, several tests will be conducted in the future such as to determine its workability and durability. Since this project is using a mortar to determine the tensile and compressive strength, then concrete can be applied in the future. Moreover, PVA can be cast together with reinforcement steel bar since both of them tend to increase the tensile strength of concrete. The mix design calculation when using PVA should be revised so that accurate results will be obtained. This can be done by trying with different concentration of polyvinyl alcohol in water such as 4%, 5% and so on. In addition, the curing age can be extended until 60^{th}, 90^{th}, 180^{th} and 360^{th} days since the samples with 2% and 3% PVA solution show high increasing rates at 28^{th} days. By doing this, the strength of mortar can be known whether it is still significant after 28^{th} days or not.

As a conclusion, polyvinyl alcohol tends to improve the bond between aggregate and cement paste hence increase the tensile strength of concrete or mortar. The optimum PVA concentration which can give higher strengths is 3% and the uses of different conditions of aggregate may affect the strengths of concrete or mortar.

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APPENDICES

APPENDIX A – 1 Suggestion Milestone for FYP1

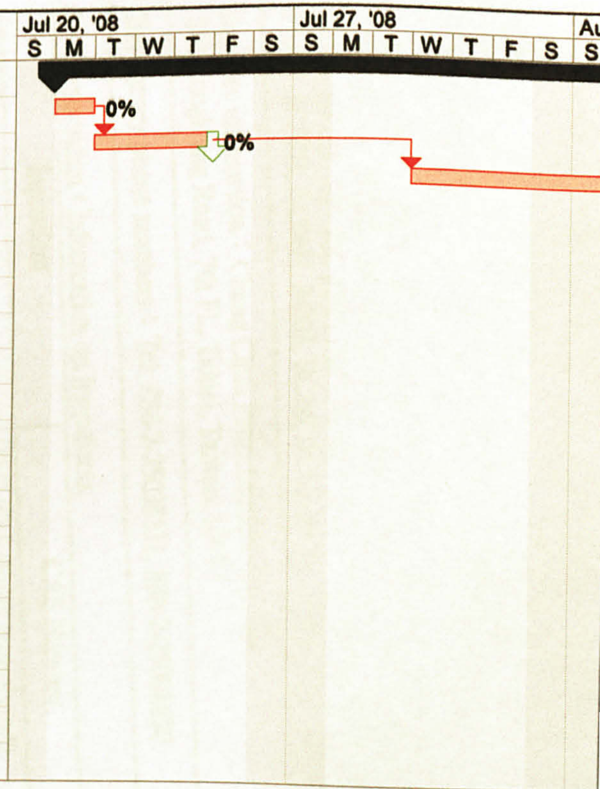
DETAIL/ WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Selection of Project Title											Mid-Semester Break				
Preliminary Research Work															
Submission of Preliminary and Progress Report															
Materials, Laboratory Works and Literature Review															
Submission of Interim Report															
Laboratory Works, Literature Review & Oral Presentation Preparation															
Oral Presentation															

APPENDIX A – 2 Suggestion Milestone for FYP2

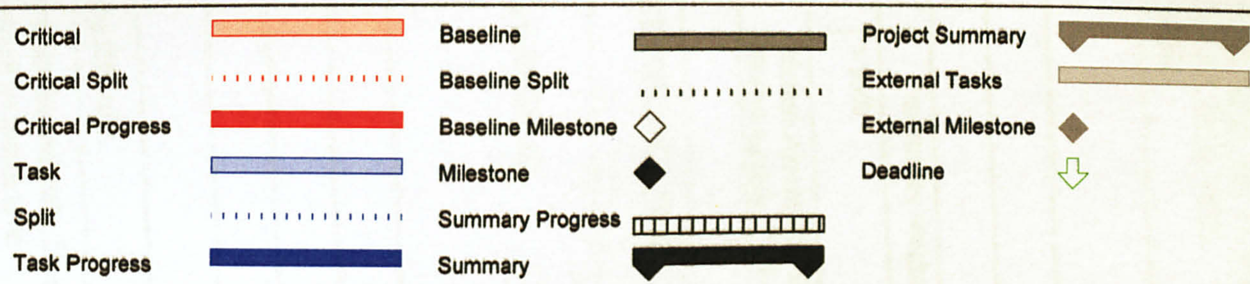
DETAIL/ WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project Work Continue										Mid-Semester Break					
Submission of Combined Progress Report															
Project Work Continue															
Poster Exhibition															
Project Work Continue															
Submission of Dissertation (Soft Bound)															
Oral Presentation															
Submission of Dissertation (Hard Bound)															

APPENDIX A-3 Gantt Chart for FYP Planning

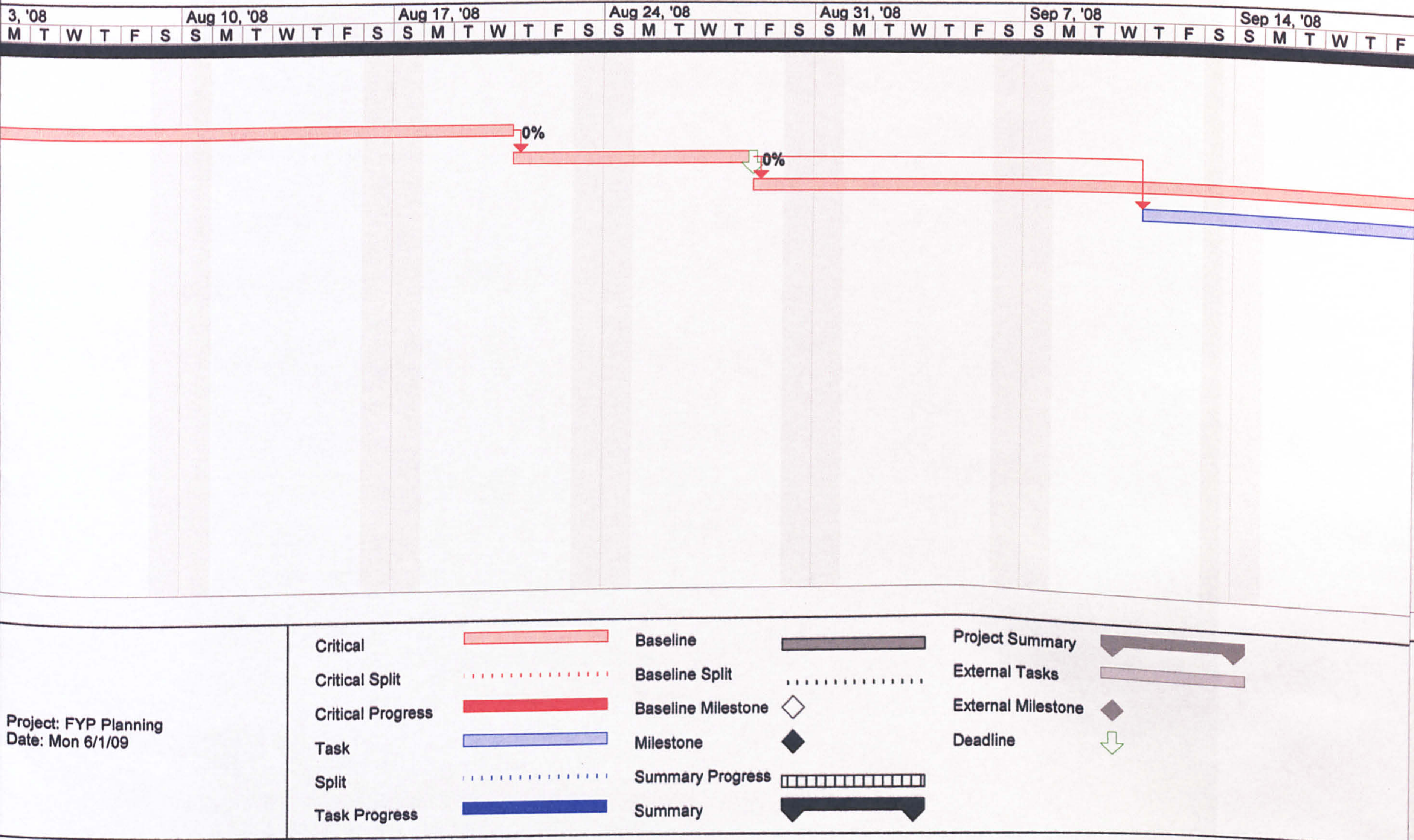
ID	Task Name	Duration	Start	Finish	Predecessors
1	**FYP**	**156 days**	**Mon 7/21/08**	**Tue 5/5/09**	
2	topic selection	1 day	Mon 7/21/08	Mon 7/21/08	
3	topic acceptance	3 days	Tue 7/22/08	Thu 7/24/08	2
4	preliminary search	16 days	Wed 7/30/08	Wed 8/20/08	3
5	prepare progress report 1	6 days	Thu 8/21/08	Thu 8/28/08	4
6	supplementary literature search 1	23 days	Fri 8/29/08	Tue 10/7/08	5
7	preliminary data collection	10 days	Thu 9/11/08	Wed 9/24/08	5
8	prepare interim report	6 days	Wed 10/8/08	Wed 10/15/08	6,7
9	oral presentation 1	5 days	Tue 10/28/08	Mon 11/3/08	8
10	lab works 1	25 days	Mon 1/12/09	Wed 2/18/09	8
11	data collect & analysis 1	2 days	Thu 2/19/09	Fri 2/20/09	10
12	prepare progress report 2	6 days	Sat 2/21/09	Thu 2/26/09	11
13	lab works 2	20 days	Fri 2/27/09	Fri 3/27/09	12
14	supplementary literature search 2	3 days	Wed 3/25/09	Fri 3/27/09	12
15	data collect & analysis 2	2 days	Mon 3/30/09	Tue 3/31/09	13,14
16	prepare poster	8 days	Wed 4/1/09	Wed 4/8/09	15
17	lab works 3	1 day	Thu 4/9/09	Thu 4/9/09	16
18	data collect & analysis 3	1 day	Fri 4/10/09	Fri 4/10/09	17
19	prepare dissertation	6 days	Sat 4/11/09	Thu 4/16/09	18
20	oral presentation 2	8 days	Tue 4/28/09	Tue 5/5/09	19



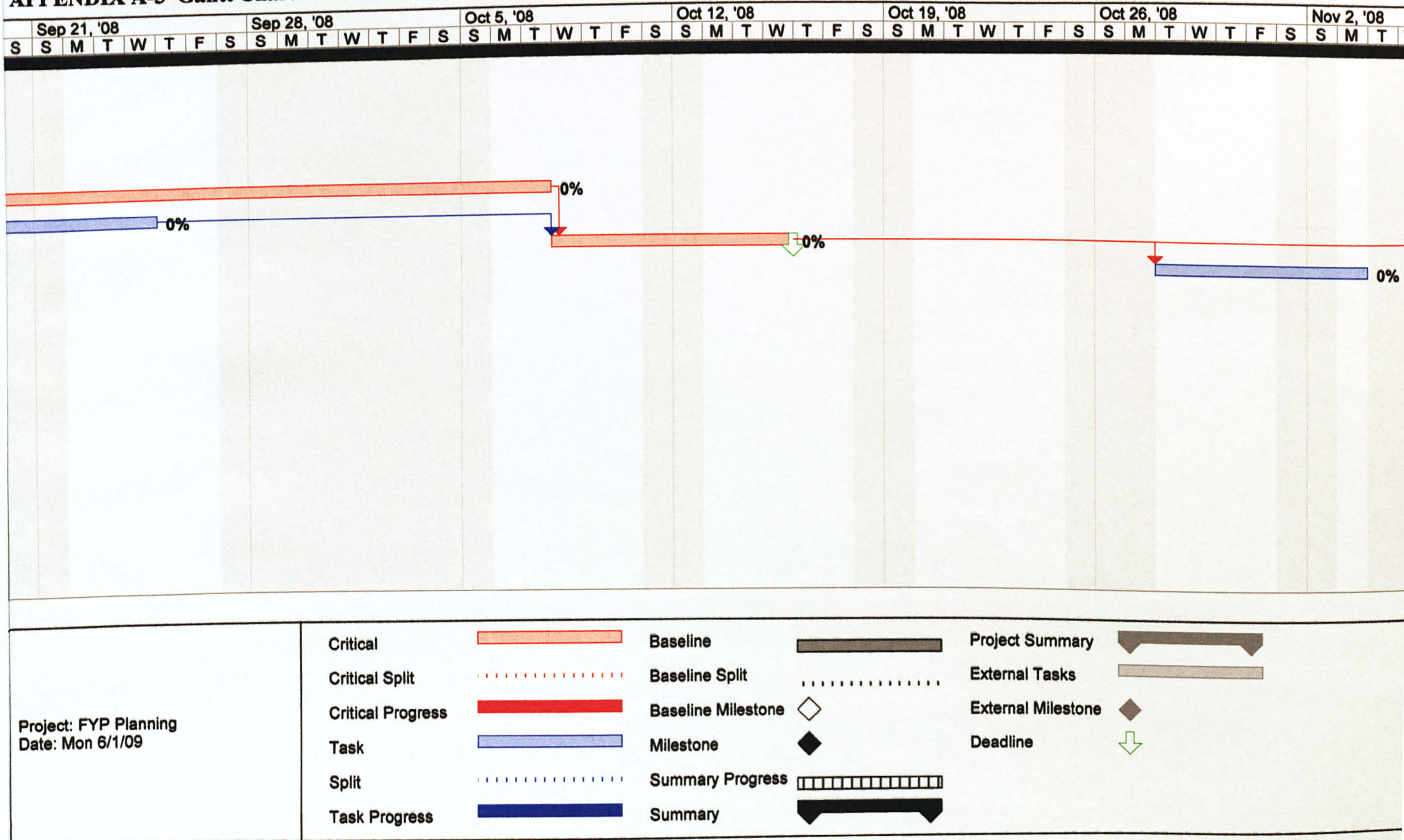
Project: FYP Planning
Date: Mon 6/1/09



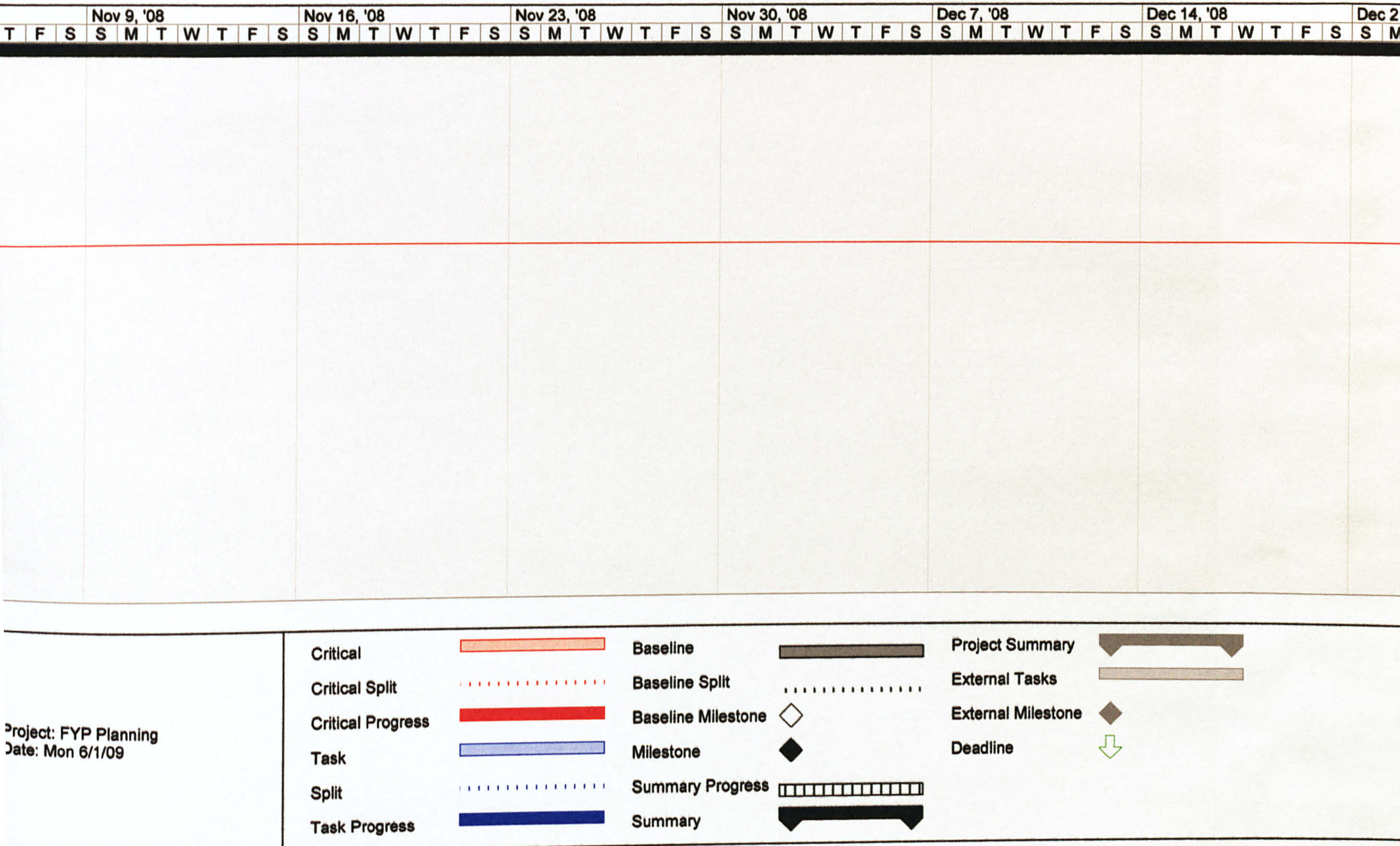
APPENDIX A-3 Gantt Chart for FYP Planning



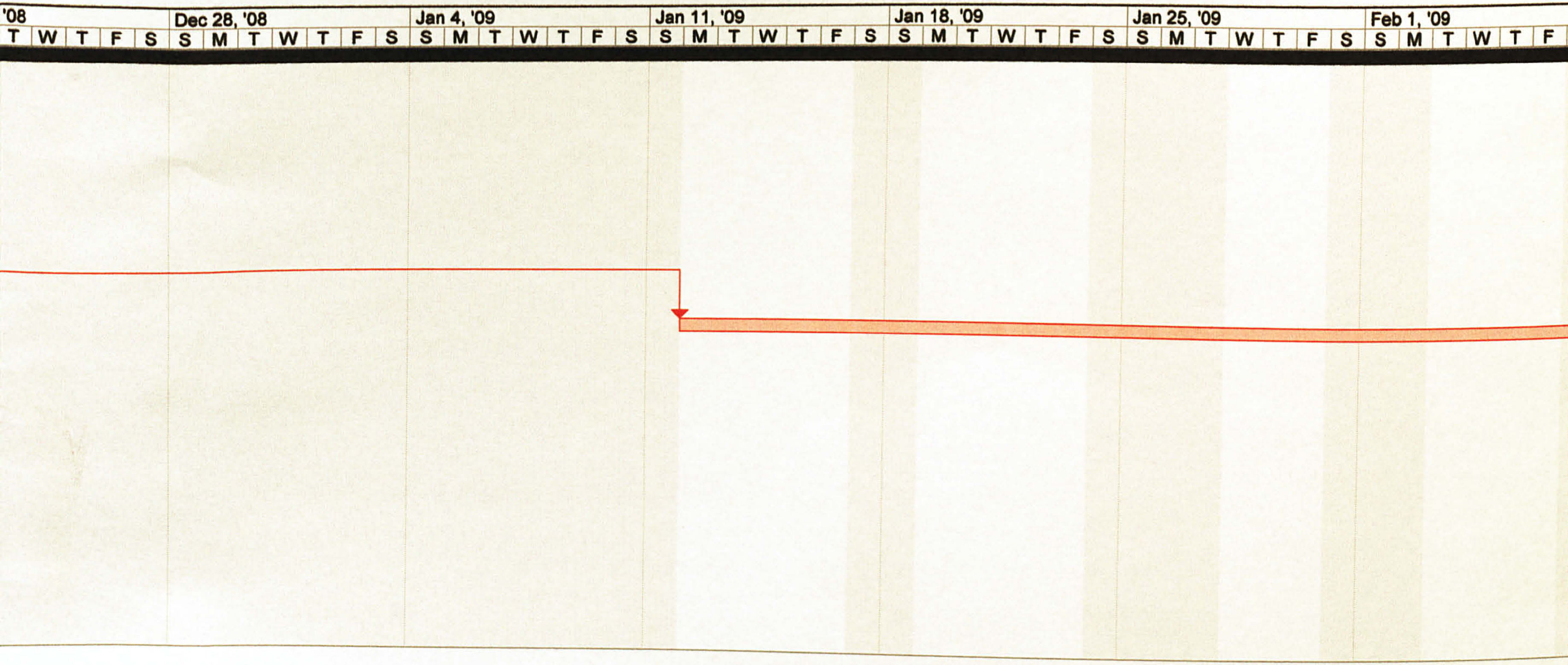
APPENDIX A-3 Gantt Chart for FYP Planning



APPENDIX A-3 Gantt Chart for FYP Planning



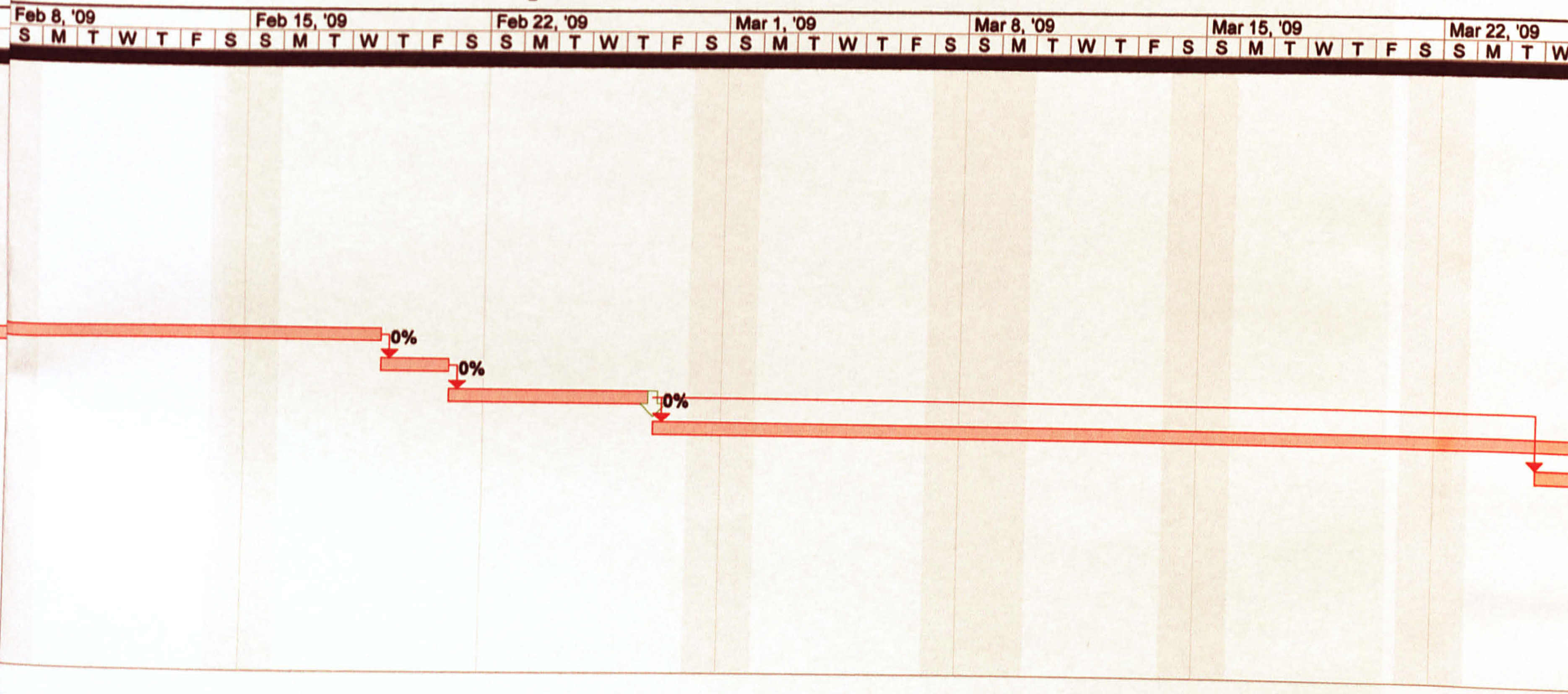
APPENDIX A-3 Gantt Chart for FYP Planning



Project: FYP Planning
Date: Mon 6/1/09

Critical	Baseline	Project Summary
Critical Split	Baseline Split	External Tasks
Critical Progress	Baseline Milestone	External Milestone
Task	Milestone	Deadline
Split	Summary Progress	
Task Progress	Summary	

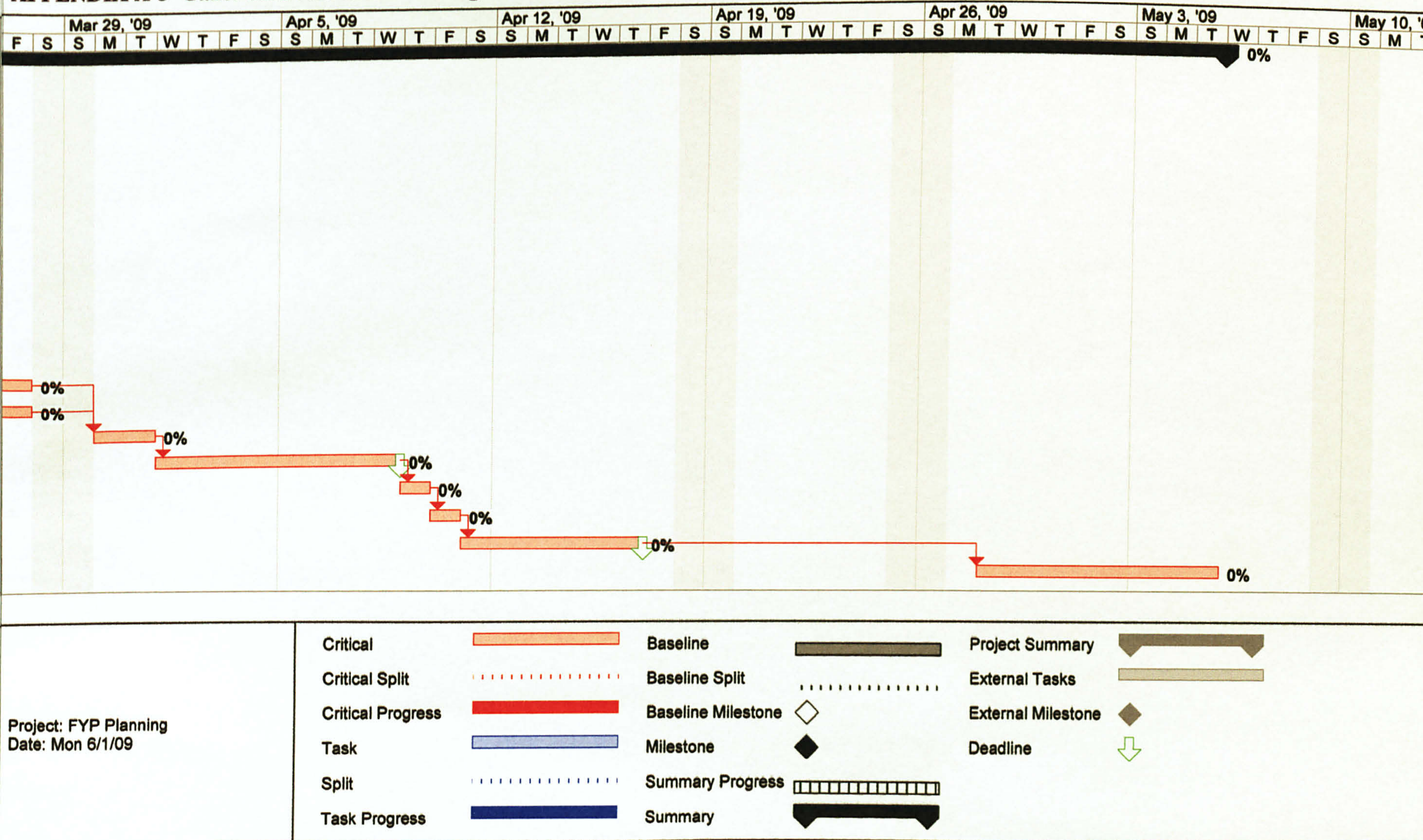
APPENDIX A-3 Gantt Chart for FYP Planning



Project: FYP Planning
Date: Mon 6/1/09

Critical		Baseline		Project Summary	
Critical Split		Baseline Split		External Tasks	
Critical Progress		Baseline Milestone		External Milestone	
Task		Milestone		Deadline	
Split		Summary Progress			
Task Progress		Summary			

APPENDIX A-3 Gantt Chart for FYP Planning



→ MR HM (Wan Cheng Plastic)

FROM · OHSY (TEXCHEM)

MATERIAL SAFETY DATA SHEET

1、Product and Company Identification

Product name： Polyvinyl Alcohol

Synonyms： PVA, PVOH, PVAL

Chemical Formula： [-CH2CHOH-]n [CH2CHOOCCH3]m

Product Codes： BP28, BP26, BP24, BP22, BP20, BP20H, BP17, BP16, BP14, BP08, BP05, BP04, BP03, BP24A, BP24S, BP20S, BP20A, BP17A, BP05A, BP17G, BP05G, BP05S, BF26, BF24, BF24H, BF24E, BF22E, BF17H, BF17, BF17E, BF17S, BF17W, BF16, BF14, BF08, BF05, BF04, BF03, BF03E, BC03H, BC04H, BC08, BC16, BC20, BC24, TS30, TP17, BP26S, BP28S

Supplier Information：Chang Chun Petrochemical Co., Ltd
301 Songkiang Road, 7th Fl., Taipei, Taiwan, 10477

Emergency phone numbers：Tel: 886-2-25038131, 886-2-25001800

2、Composition / Information on Ingredients

Ingredient	CAS Number	Percent (by weight)
Polyvinyl Alcohol	9002-89-5 (Fully hydrolyzed) 25213-24-5 (Partially hydrolyzed)	> 95%
Methyl Alcohol Methyl Acetate	Methyl Alcohol:67-56-1 Methyl Acetate:79-20-9	Methyl Alcohol:< 3% Methyl Acetate:< 1%

3、Hazards Identification

Emergency Overview： CAUTION! MAY FORM COMBUSTIBLE DUST CONCENTRATIONS IN AIR. NUISANCE DUST.

Adverse Human Health Effects：
Inhalation:Dust may be formed under certain conditions of use. Treat as a nuisance dust.
Ingestion:Not expected to be a health hazard via ingestion.
Skin Contact:Not expected to be a health hazard from skin exposure.
Eye Contact:Mechanical irritation only.

Environmental Effects： No information available

Physical and Chemical Hazards： No information available

Specific Hazards： No information available

4、First-Aid Measures

Inhalation： Remove to fresh air. Get medical attention for any breathing difficulty.

Ingestion： If large quantities of this material are swallowed, call a physician immediately. Do not induce vomiting unless directed to do so by a physician. Never give anything by mouth to an unconscious person. Get medical attention.

Skin Contact : Wash exposed area with soap and water.

Eye Contact : Wash thoroughly with running water. Get medical advice if irritation develops.

Protection of First-aiders : No information available

Notes to Physician : No information available

5 · Fire-Fighting Measures

Extinguishing Media : As with most organic solids, fire is possible at elevated temperatures or by contact with an ignition source. Minimum dust cloud ignition temperature: 440°C.

Fire and Explosion Hazards : Fine dust dispersed in air in sufficient concentrations, and in the presence of an ignition source is a potential dust explosion hazard. Minimum explosion concentration 35 g/m3. Maximum explosion pressure: 6.26 kg/cm2.

Special Firefighting Procedures : Not required.

Special Equipment for the Protection of Firefighters : In the event of a fire, wear full protective clothing and NIOSH-approved self-contained breathing apparatus with full facepiece operated in the pressure demand or other positive pressure mode.

6 · Accidental Release Measures

Personal Precautions : Remove all sources of ignition. Ventilate area of leak or spill. Wear appropriate personal protective equipment as specified in Section 8.

Environmental Precautions : Spills: Clean up spills in a manner that does not disperse dust into the air. Use non-sparking tools and equipment. Reduce airborne dust and prevent scattering by moistening with water.

Methods for Cleaning Up : Pick up spill for recovery or disposal and place in a closed container.

7 · Handling and Storage

Handling : Avoid dust formation and control ignition sources. Employ grounding, venting and explosion relief provisions in accord with accepted engineering practices in any process capable of generating dust and/or static electricity.

Storage : Keep in a tightly closed container, stored in a cool, dry, ventilated area. Protect against physical damage. Separate from incompatibilities.

8 · Exposure Controls / Personal Protection

Engineering Measure : Airborne Exposure Limits
OSHA Permissible Exposure Limit (PEL):
15 mg/m3 total dust, 5 mg/m3 respirable fraction for nuisance dusts.
ACGIH Threshold Limit Value (TLV):
10 mg/m3 total dust containing no asbestos and < 1% crystalline silica for Particulates Not Otherwise

Classified (PNOC).
Control parameters : • Limit values : No information available • Biological Standards : No information available
Personal Protective Equipment : • Respiratory Protection : If the exposure limit is exceeded, a half-face dust/mist respirator may be worn for up to ten times the exposure limit or the maximum use concentration specified by the appropriate regulatory agency or respirator supplier, whichever is lowest. • Hand Protection : NA • Eye Protection : Use chemical safety goggles. • Skin and Body Protection : Wear protective gloves and clean body-covering clothing.
Specific Hygiene Measures : No information available

9 · Physical and Chemical Properties

Physical State : solid	Form : White to ivory granule or powder
Color : White to ivory	Odor : Mild odor.
pH : 5~7 (4% solution)	Boiling Point/Boiling Range : No information.
Decomposition Temperature : >220℃	Flash Point & Method Used : NONE
Auto Ignition Temperature : NONE	Explosion Properties : Minimum explosion concentration 35 g/m3. Maximum explosion pressure: 6.26 kg/cm2.
Vapor pressure : No data.	Vapor density : No data.
Density : 1.23 - 1.31	Solubility : Moderately soluble.

10 · Stability and Reactivity

Stability : Stable under ordinary conditions of use and storage.
Possible Hazardous Reactions Occurring under Specific Conditions : Hazardous polymerization will not occur.
Conditions to Avoid : Heat, flame, ignition sources, dusting and incompatibles.
Materials to Avoid : Strong oxidizers.
Hazardous Decomposition Products : Complete combustion will emit carbon dioxide and water when heated to decomposition. Incomplete combustion gives in addition carbon monoxide and oxidation products, including organic acids, aldehydes and alcohol.

11 · Toxicological Information

Acute toxicity : Oral rat LD50: > 5000 gm/kg; practically nontoxic to animals by ingestion.

To Be Returned
To Master File

Local effects : Inhalation LC50:>20.0 mg/l (rats; dust with 3-5 micron particle size; 1 hr. exposure); practically nontoxic to animals by acute inhalation exposure.
Skin:In powder form, Polyvinyl Alcohol was nonirritating to rabbit skin. In aqueous solution, slight irritation to rabbit skin was noted.

Sensitization : Not a skin sensitizer in guinea pigs when dosed as a 10% aqueous solution. Practically nontoxic to animals (LD50, rabbits: >1,000 mg/kg).
Eye: The powder and aqueous solutions are slightly irritating to rabbit eyes; irritation subsided by 48 hrs after exposure.

Chronic Toxicity or Long Term Toxicity : Polyvinyl Alcohol is not classifiable as to (its) carcinogenicity in humans".

Specific effects : No information

12 · Ecological Information

Possible Environmental Effects, Behavior and Fate :
Polyvinyl alcohol exhibits low acute toxicity to aquatic species.
Fish (Pimephales promelas) 96-hr. LC50: > 40,000 ppm.
Fish (Lepomis macrochirus) 96-hr. LC50: >10,000 ppm.
Bacteria (Photobacterium phosphoreum), Microtox Method. EC50: >50,000 ppm.
Polyvinyl alcohol (PVOH) has been reported to be substantially biodegraded in several test systems after a lag time for microbial acclimation. Almost 100% degradation of 30-day BOD with a PVOH-acclimated culture can be reached.

13 · Disposal Considerations

Recommended Methods for Safe and Environmentally Preferred Disposal : Whatever cannot be saved for recovery or recycling should be managed in an appropriate and approved waste disposal facility. Dispose of as a non-hazardous solid waste.

14 · Transport Information

International regulations : This product is not classified as dangerous goods according to the international regulations for transport by land, inland waterway, sea and air.

UN classification number : none , PVA is non-hazardous material according to IATA

Specific Precautionary Transport Measures and Conditions : This product is not classified as dangerous goods according to the international regulations for transport by land, inland waterway, sea and air.

15 · Regulatory Information

Applicable Regulations :

Ingredient\Area	TSCA	EC	Japan	Australia
Methyl Alcohol (67-56-1)	Yes	Yes	Yes	Yes
Polyvinyl Alcohol (9002-89-5)	Yes	No	Yes	Yes

16 · Other Information

NFPA Ratings	Health: 0, Flammability: 1, Reactivity: 0
Label Hazard Warning	CAUTION! MAY FORM NUISANCE DUST.
Literature References	

APPENDIX C Mix Design Calculations

Aggregate to cement ratio = A : C = 2 : 1
Water to cement ratio = W : C = 0.35
Concrete density = 2400 kg / m^3

Assume W = 1;

A : C : W

W / C = 0.35
C = 2.86

Hence, **A : C : W = 5.72 : 2.86 : 1 (Total fraction = 9.58)**

For cylinder mould dimensions, taking Ø = 0.06m and h = 0.12m

1 cylinder; $V = \pi r^2 h$
$= \pi(0.03)^2(0.12)$
$= 3.393 \times 10^{-4}\ m^3$

21 cylinders; $V = 3.393 \times 10^{-4} \times 21$
$= 7.125 \times 10^{-3}\ m^3$

Mass = density x volume
$= 2400 \times 7.125 \times 10^{-3}$
= 17.10 kg

Mass for each proportion;

Aggregate = (5.72 / 9.58) x 17.10
= 10.21 kg

Cement = (2.86 / 9.58) x 17.10
= 5.11 kg

Water = (1 / 9.58) x 17.10
= 1.78 kg

PVA mass (based on water mass)

1% = **17.80 g**
2% = **35.60 g**
3% = **53.40 g**

APPENDIX D Procedures

a. Aggregate Preparation

i. Arrange the sieve according to its sizes and carry out the sieving for about 15 minutes.
ii. Wash the aggregate to remove the grass and unnecessary things.
iii. Soak for one day in order to achieve the **saturated surface dry (SSD)** aggregate.
iv. Remove the water. Let them dry.
v. For **dry aggregate,** place it in the oven for two hours at 60°C before mixing.

b. Mould Preparation

i. Clean the cylinder mould and apply the grease inside the end cap.
ii. Place the cap at the end of the cylinder.

c. PVA Solution Preparation

PVA comes in powder form. Here, 20% concentration of PVA solution is desires to be prepared. Hence, conventional heating method is used. The procedure is as below:

i. Heat one liter of distilled water up to 88 – 90°C on the hot plate with magnetic stirrer.
ii. Once the water is heated, add lightly the PVA into the water while stirring continuously. This is very important to avoid the gooey mass of wet polymer that sticks together, settle out and clings to the wall of the beaker. Avoid overheating the solution.
iii. Allow the solution to cool once it is completely dissolve.

d. Mixing

In mixing process, different concentration of PVA is used. They are 1%, 2% and 3% concentration based on the weight of water to cement ratio. The mixing was conducted as below:

i. Clean the mixer drum with water so that the mixing water will not be absorbed by drum.
ii. Pour all fine aggregate and cement into the mixer and mix for two minutes.
iii. Pour half of water with PVA solution and mix for two minutes. Make sure that PVA solution is completely dissolved in water.
iv. Pour another half of water with PVA solution and mix for two minutes.
v. Perform a hand mixing and mix again for two minutes.

e. Moulding and Demoulding

i. Cast the mixing by one – third of the cylinder mould.
ii. Perform the vibrating table to eliminate the bubble inside the mortar.
iii. Repeat Step i and ii for another two times and leave it for 24 hours. After that, open the mould and store the samples in the curing tank.

APPENDIX E – 1 Compression and Tension Test Results for Control

SPLIT TENSILE TEST

DAY	3			7			28		
	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)
S1	674.27	44.8	4.240	694.74	29.2	2.720	693.04	10.2	0.934
S2	700.71	36.0	3.312	691.89	32.0	3.017	709.65	33.1	2.976
S3	711.79	28.1	2.556	714.79	39.9	3.645	720.35	32.1	2.905
Average		36.3	2.556		33.7	2.869		25.1	2.941

COMPRESSION TEST

DAY	3			7			28		
	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)
S1	704.10	34.3	14.76	704.53	33.0	13.97	685.08	9.1	3.95
S2	714.12	31.5	13.29	713.39	42.5	17.85	723.71	44.9	18.77
S3	705.40	38.0	16.45	710.92	39.4	16.84	712.54	42.4	18.00
Average		34.6	14.833		38.3	16.220		32.1	18.385

SUMMARY

	TEST	
Day	Tensile	Compression
3	2.556	14.833
7	2.869	16.220
28	2.941	18.385

APPENDIX E – 2 Compression and Tension Test Results for Mix 1% PVA + SSD

SPLIT TENSILE TEST

DAY	3			7			28		
	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)
S1	693.13	30.1	2.762	694.70	30.3	2.772	655.64	47.7	4.608
S2	683.57	32.0	2.988	696.80	35.8	3.304	648.26	41.6	3.967
S3	695.43	49.5	4.597	678.50	46.0	4.287	640.61	54.5	5.390
Average		37.2	2.875		37.4	3.796		47.9	4.655

COMPRESSION TEST

DAY	3			7			28		
	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)
S1	693.41	36.6	15.52	695.30	23.8	10.10	633.01	56.5	23.38
S2	698.93	38.2	15.92	697.00	45.7	18.87	658.16	87.9	36.64
S3	693.77	44.6	18.62	705.00	40.8	17.19	627.16	65.2	27.88
Average		39.8	16.687		36.8	18.030		69.9	29.300

SUMMARY

	TEST	
Day	Tensile	Compression
3	2.875	16.687
7	3.796	18.030
28	4.655	29.300

APPENDIX E – 3 Compression and Tension Test Results for Mix 2% PVA + SSD

SPLIT TENSILE TEST

DAY	3			7			28		
	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)
S1	695.91	38.1	3.490	677.93	27.7	2.572	654.35	58.0	5.615
S2	688.94	20.2	1.847	686.52	28.6	2.680	692.06	32.5	3.013
S3	691.19	27.7	2.547	700.98	27.4	2.507	692.82	48.4	4.574
Average		28.7	2.628		27.9	2.680		46.3	5.095

COMPRESSION TEST

DAY	3			7			28		
	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)
S1	682.16	26.9	11.56	699.18	35.6	15.11	694.84	43.40	18.12
S2	705.10	10.3	4.29	691.54	33.8	14.30	635.70	121.20	50.70
S3	680.04	30.8	12.82	680.99	39.6	17.04	642.89	112.10	47.62
Average		22.7	9.556		36.3	15.483		92.2	49.160

SUMMARY

	TEST	
Day	Tensile	Compression
3	2.628	9.556
7	2.680	15.483
28	5.095	49.160

APPENDIX E – 4 Compression and Tension Test Results for Mix 3% PVA + SSD

SPLIT TENSILE TEST

DAY	3			7			28		
	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)
S1	708.57	41.0	3.741	707.74	43.1	3.894	664.41	52.7	5.087
S2	704.00	32.9	3.033	695.01	35.5	3.267	678.45	41.5	3.913
S3	707.30	45.2	4.107	709.13	36.7	3.237	676.60	61.8	5.846
Average		39.7	3.387		38.4	3.466		52.0	5.467

COMPRESSION TEST

DAY	3			7			28		
	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)
S1	699.56	26.4	11.03	705.52	23.9	9.95	696.87	70.1	29.51
S2	689.56	21.5	8.97	702.12	30.1	12.53	633.09	100.1	41.04
S3	706.43	24.9	10.42	680.17	38.5	16.28	646.55	128.9	53.83
Average		24.3	10.140		30.8	12.921		99.7	53.830

SUMMARY

	TEST	
Day	Tensile	Compression
3	3.387	10.140
7	3.466	12.921
28	5.467	53.830

APPENDIX E – 5 Compression and Tension Test Results for Mix 1% PVA + DRY

SPLIT TENSILE TEST

DAY	3			7			28		
	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)
S1	697.70	13.7	1.251	692.53	36.4	3.359	652.83	51.3	5.099
S2	669.42	25.8	2.417	705.20	54.1	4.916	631.24	40.0	4.070
S3	689.46	29.4	2.734	705.78	38.6	3.497	650.59	35.8	3.547
Average		23.0	2.5755		43.0	3.924		42.4	4.239

COMPRESSION TEST

DAY	3			7			28		
	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)
S1	714.98	30.6	12.67	691.20	45.3	19.19	643.92	77.9	32.77
S2	674.95	32.2	13.71	682.35	37.3	15.96	644.86	108.7	45.94
S3	673.65	35.8	14.98	694.22	41.8	17.39	672.59	68.7	28.91
Average		32.9	13.787		41.5	17.513		85.1	35.873

SUMMARY

	TEST	
Day	Tensile	Compression
3	2.576	13.787
7	3.924	17.513
28	4.239	35.873

APPENDIX E – 6 Compression and Tension Test Results for Mix 2% PVA + DRY

SPLIT TENSILE TEST

DAY	3			7			28		
	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)
S1	679.88	35.1	3.197	692.36	9.1	0.826	629.09	54.4	5.482
S2	683.32	39.5	3.575	684.16	35.6	3.233	640.32	48.9	4.841
S3	660.83	27.3	2.593	683.98	35.1	3.199	643.34	50.1	4.946
Average		34.0	3.122		26.6	3.216		51.1	5.090

COMPRESSION TEST

DAY	3			7			28		
	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)
S1	677.04	36.2	15.33	687.82	41.5	17.15	657.60	112.4	47.63
S2	699.51	34.4	14.24	692.08	45.3	18.80	639.61	40.4	17.26
S3	641.24	38.2	16.26	685.56	46.0	19.41	651.56	56.4	23.81
Average		36.3	15.277		44.3	18.453		69.7	29.567

SUMMARY

	TEST	
Day	Tensile	Compression
3	3.122	15.277
7	3.216	18.453
28	5.090	29.567

APPENDIX E – 7 Compression and Tension Test Results for Mix 3% PVA + DRY

SPLIT TENSILE TEST

DAY	3			7			28		
	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)
S1	662.11	52.8	5.001	652.46	52.2	5.024	648.04	65.2	6.377
S2	695.79	32.6	2.959	653.37	32.4	3.163	625.15	55.2	5.624
S3	675.65	31.6	2.970	664.97	51.9	4.943	633.26	54.3	5.454
Average		39.0	3.643		45.5	4.377		58.2	5.818

COMPRESSION TEST

DAY	3			7			28		
	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)	Weight (g)	Max. Load (kN)	Stress (N/mm^2)
S1	675.33	38.2	15.97	609.43	27.5	11.63	621.68	77.4	32.24
S2	672.54	44.2	18.49	652.48	49.0	20.54	646.50	97.6	40.67
S3	669.96	37.0	15.54	682.54	52.9	22.64	648.99	117.0	49.42
Average		39.8	16.667		43.1	18.270		97.3	40.777

SUMMARY

	TEST	
Day	Tensile	Compression
3	3.643	16.667
7	4.377	18.270
28	5.818	40.777